II SECA Industry Teams

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II.1 Development of a Low-Cost 10-kW Tubular SOFC Power System

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Objectives

- Design a common low-cost generator to meet all chosen markets.
- Develop an anode-supported micro-tubular cell capable of twice the power density presently achieved.
- Design, build, and test an inverter with 94% efficiency for conversion from direct current (DC) to alternating current (AC).
- Test prototype of a natural gas fueled unit meeting and exceeding Solid State Energy Conversion Alliance (SECA) goals.

Approach

- Increase the current collection points per tube to increase cell power.
- Improve anode conductivity and stability to allow a greater power per unit length of cell tube.
- Decrease solid oxide fuel cell (SOFC) generator component costs through advanced manufacturing techniques.
- Perform preliminary testing on liquid fuels to determine critical operating parameters.
- Develop the AC/DC high-efficiency conversion end building off our existing 98% efficient DC/DC regulator.

Accomplishments

- *Demonstrated Cell Power Density Increases from 150 to 297 mW/cm^2:*
  Different geometry cells have been manufactured and tested showing the viability of doubling the power per tube. This has been accomplished by adjusting the anode tube chemistry while also changing the number of current collection points on the tube. This accomplishment has the ability to cut the required number of tubes per kilowatt in half and also dramatically reduce the size of the fuel cell generator.
- *Implemented Advanced Generator Manifolds Reducing Cost by over $1000/kW:*
  One of the first advanced manufacturing techniques pursued to decrease overall cost of the SOFC generator was validated. A metal injection molding (MIM) process that was previously only capable of making low-temperature aluminum parts was developed to net shape cast high-temperature metal parts. This process allows for the saving of many labor hours of machining and overall cost reduction of the SOFC generator.

- *Demonstrated Generator Operation on Diesel and Synthetic Diesel Fuel:*
  A 5-kW SOFC generator has been tested and proven to operate successfully on liquid diesel fuel. This unit also operated on synthetic diesel fuel made by renewable domestic sources. The unit was baseline tested on natural gas and found to have nearly identical performance on liquid fuels as on natural gas.
- *Demonstrated an Advanced Heat Exchanger Capable of Meeting SECA Phase I Cost Targets:*
  During the past year, a number of advanced heat exchangers have been tested. A heat exchanger design that integrates the geometries of a shell and tube heat exchanger and a flat plate heat exchanger has achieved high electrical efficiency and low cost.
- *Independent Audit of SECA Phase I Cost and Performance Goals Successfully Completed:*
  In keeping with the Government Performance and Results Act, an independent audit of the Acumentrics program was completed by Spencer Management Associates and Argonne National Laboratory to determine the technical risk of meeting the SECA Phase I cost and performance targets. The program requires achieving <$800/kW and stable operation over 1500 hours to pass the first gate of the program. It was determined that Acumentrics should exceed the cost targets, and the probability of achieving performance goals is high.

Future Directions

- *Complete Full-Scale Testing of Multiple Current Collection Cells:*
  Preliminary testing has been completed on a number of cells showing multiple electrical take-offs. Further work is required to electrically test a number of these cells to demonstrate long-term stability as well as repeatability and thermal cycle toughness. Upon completion of this testing, cells will be validated for production and utilization in the Phase I test unit.
- *Complete 95%-Efficient Inverter Development:*
  With the integration of an inverter capable of over 95% efficiency versus the market standard of 82-90%, overall system efficiencies can rise by nearly 5 percentage points. This improvement in overall efficiency can be equated to fuel savings to reduce the overall cost of electricity. Another option is to operate the fuel cell stack at a lower cell voltage point, thereby increasing the individual cell power and reducing the number of fuel cells and the overall capital cost.
- *Complete SECA Phase I Generator Performance Testing:*
  The SECA Phase I generator design is nearing completion, and key components are going through validation testing at this time. As these tests are completed, the final bill of materials will be generated for the prototype machine. The machine will be built during the next year, and a test plan will be finalized between Acumentrics and the DOE project manager. The unit will then be tested according to this plan.

Introduction

The Acumentrics SECA program has focused on the design and manufacture of micro-tubular SOFC power systems approaching twice the power density now achieved with state-of-the-art anode-supported tubular designs. As a result of DOE funding and a focused research effort, these cells are now very near to achieving this goal. These units will be capable of entry into the telecommunication, remote residential, and military markets. Operation on fuels including natural gas and propane will be developed for the telecommunication and remote residential markets. Operation on liquid fuels, including diesel and JP-8, will be developed for the military markets.

Working with Acumentrics to define market segments and market requirements are a number of key investors that are strategic players in their respective markets. They include:

- Chevron for remote markets and liquid fuels.
- General Dynamics for liquid fuels as well as military operations.
- Northeast Utilities and NiSource for integration in the natural gas and electricity infrastructure.
- Sumitomo Corporation of Japan for product definition and introduction into the Japanese market.

Approach

To achieve the final SECA goal of a manufactured unit cost of less than $400/kW, work can focus on increasing cell power, thereby decreasing the number of cells per kilowatt, or it can focus on decreasing the cost of each component. With such an aggressive goal, work must address both paths. To increase cell power, work is centered on improved materials as well as enhancements in geometry. Cells with increased anode conductivities to decrease electrical bus losses are being investigated. Improved conductivity of cathodes is also being investigated to decrease the potential loss associated with the electrochemical reaction on the airside. Increases in cell tube diameter as well as multiple contact points along the length are also being studied.

For subsystem cost reductions, the machine is divided into four major sub-systems: the SOFC generator, the control system, the power conditioning system, and the fuel and airflow system. In the SOFC generator, advanced materials and manufacturing techniques are being investigated, including metal injection molding (MIM) as well as metal stampings. Vacuum cast insulation to near net shape is also being considered. For the control system, a Controller Area Network bus architecture is being developed, and control of all valves and power electronics is being integrated. For the power electronics sub-system, the focus is on improving the overall DC/AC conversion efficiency to avoid excessive losses which compromise overall system efficiency and require more cells and therefore more cost. In the air and fuel sub-system, removal of redundant components as well as qualification of equivalent components at lower cost is the path chosen.

Results

In an attempt to increase the overall power per cell, work has focused on optimizing the geometry of the fuel cell as well as the performance of the individual layers. Work on the anode tube has comprised changes in the overall composition to improve conductivity as well as introduction of higher-conductivity internal layers. Over the past year, cells with higher-conductivity internal layers

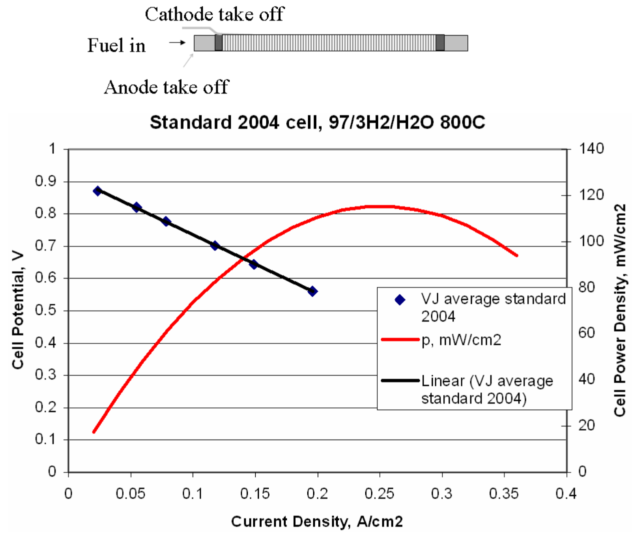

Figure 1. Standard Cell Performance

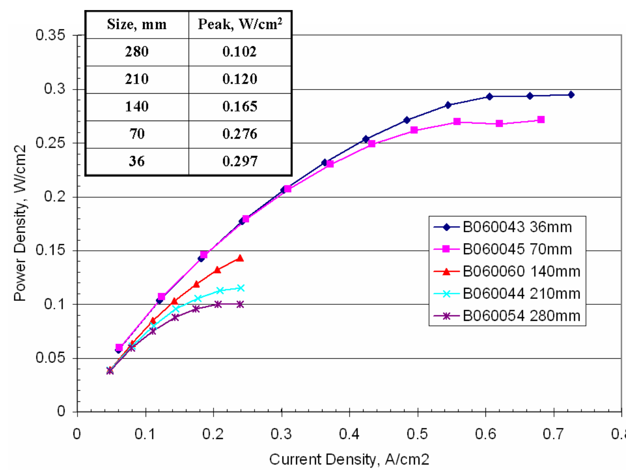

Figure 2. Power Density Advancements (800°C, 75% fuel utilization)

have achieved substantial power gains. Cells have now completed over one year's continuous testing. During that one year of testing, the degradation has been less than 1%/500 hours, which is substantially better than the SECA Phase I requirement of 2%/500 hours.

In addition to improved anode conductivity, work has focused on cell geometry and multiple take-off connections. Since the current Acumentrics design requires power take-off at a single end, the peak power density remains at 115 mW/cm^2, as seen in Figure 1. To determine length effects, multiple cells of increasing length were tested. As seen in Figure 2, the peak power density approaches 300

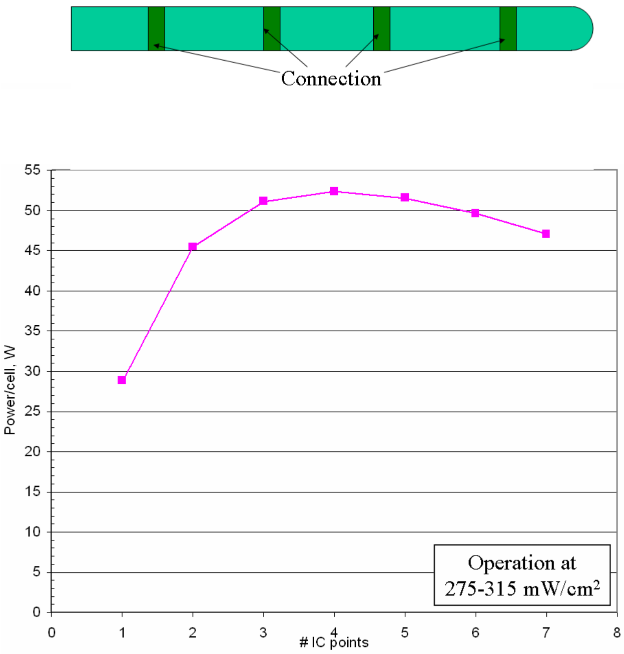

Figure 3. Multiple Take-off Cell

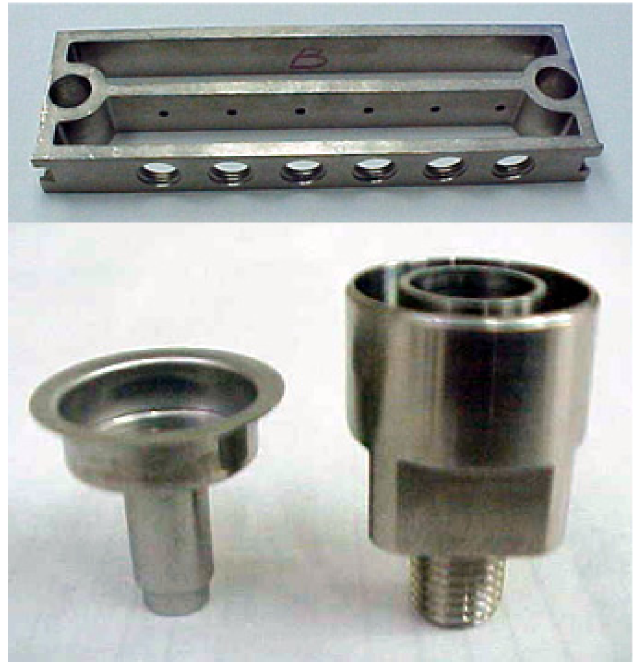

Figure 4. MIM Manifold & Cap Samples

mW/cm^2 as the overall length decreases from 280 mm to 36 mm. To take advantage of this phenomenon, a tube must be designed with multiple take-offs, allowing for longer-length tubes achieving the power density of shorter-length tubes. Figure 3 shows such a tube design which analytically has been shown to achieve greater than 50 W, or nearly 300 mW/cm^2. This cell design is presently being fabricated and undergoing initial high-temperature testing. If fabrication is successful, the existing SOFC generators will be able to achieve the same power level with 50-65% fewer fuel cells, resulting in significant cost and size savings.

On the topic of advanced manufacturing for generator components, a number of significant accomplishments can be reported. Metal injection molded manifolds have been fully validated for performance at high temperatures. The MIM process allows for intricate shapes, such as the fuel manifolds for SOFCs, to be made in a process similar to that of injection molded plastics. To date, this process has been limited to simple aluminum components, but through research with a number of vendors, application of the process has been expanded to include parts made of high-temperature alloys. Figure 4 shows not only the manifold but also the braze cap made from the MIM process. This advancement reduces the cost of the total SOFC generator by nearly $2000/kW and provides a process capable of meeting the SECA cost targets.

Another advancement in generator components has been in the thermal recovery area. Tests have been performed on both ceramic and metallic heat exchangers with reasonable success. Metallic recuperators have been designed by combining the positive features of both shell and tube as well as flat plate heat exchangers. This new design allows for high thermal effectiveness, which aids overall system electrical efficiency, resulting in low overall cost. The unit also results in low pressure drop, allowing it to be easily integrated into the existing natural gas fuel infrastructure located in the United States without the need for costly and inefficient boost compressors. At the same time, ceramic heat exchangers have been designed and tested which would provide a further cost reduction beneficial to the later stages of the SECA program. These units to date have performed reasonably well on thermal cycle testing but have not achieved the overall thermal effectiveness needed for the design. Further work will concentrate on improving that thermal effectiveness through changes in the airflow geometry.

To boost the overall system efficiency, a DC/AC inverter was further advanced which has an overall conversion efficiency of over 94%. This unit, when fully developed, has the ability to replace an existing inverter package that is 86-87% efficient. This would then result in a boost in overall generator system efficiency of over 3 points. Another advantage of this design is the usage of many components being developed for the 48V automotive conversion which is occurring at this time. This will allow for leveraging of the volume cost reductions seen in the automotive industry into the fuel cell industry.

Conclusions

Continual advancements have been made toward the SECA cost and performance targets in the Acumentrics SOFC program. Cell power advancements outlined before the program have been achieved. Cost reductions in certain key fuel cell stack components have been validated and implemented in demonstration units. Further work on all of these tasks will be performed to achieve the ultimate goal of $400/kW.

FY 2005 Publications/Presentations

1. "Status of the Acumentrics SOFC Program", N.F. Bessette, Presented at the Annual SECA conference, Pacific Grove, CA., April 18, 2005.